Sediment Transport & Geomorphology

- Objectives
  - Learn basic concepts of sediment transport and fluvial geomorphology
  - Understand sediment budgets (sources, sinks, pathways for sediment)
  - Discuss infrastructure and ecosystem response

Sediment Transport and Geomorphology in Planning Steps

- Characterize Physical Attributes of
  - Existing conditions
  - Reference conditions
  - Future w/o project conditions
  - Alternatives

- 70% of ecosystem restoration efforts are linked to sediment and geomorphology

Sediment Transport & Geomorphology

- Sediment Transport
  - mechanics of sediment erosion, transport, and deposition by water
- Geomorphology
  - geologic science of landscape formation

- H&H is the big driver affecting sediment transport and geomorphology

Too Much/Too Little Sediment

- Problems with too much sediment
  - Raised flood profiles
  - Reduced underwater light
  - Decreased capacity of hydraulic structures
- Problems with too little sediment
  - Incision (channel lowering)
  - Delta loss
  - Scour at hydraulic structures

Sediment Size

- Clay < 0.004 mm
- Silt 0.004 - 0.0625 mm
- Sand 0.0625 - 2 mm
- Gravel > 2mm

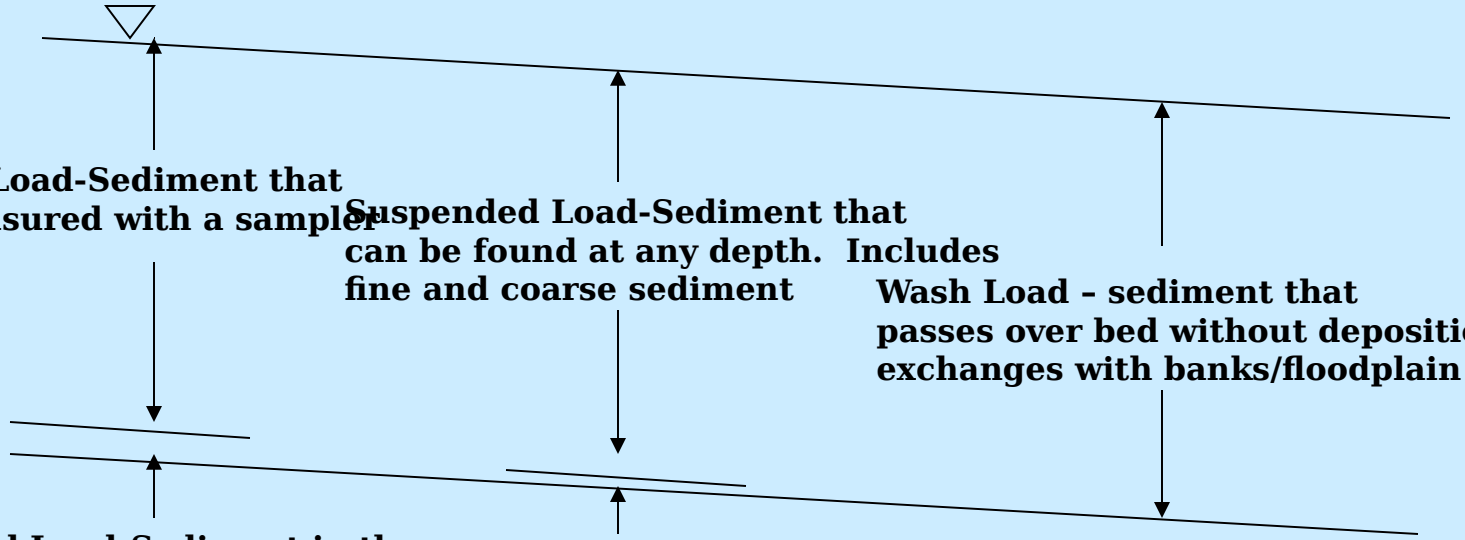
- The larger the sediment particle, the less readily it is picked up by flow at a given speed, and if picked up, the shorter the distance it is likely to travel before re-settling
- Clay and silt are considered fine sediments
- Sand and gravel are considered coarse sediment
- Note: Protocols for cobble bed mountain streams may differ, where fines may be considered anything less than 5.6 mm.

Descriptions of Sediment Load

Ability to Measure

Mode of Transport

Location in River



Measured Load-Sediment that can be measured with a sampler

Suspended Load-Sediment that can be found at any depth. Includes fine and coarse sediment

Wash Load – sediment that passes over bed without deposition. exchanges with banks/floodplain

Un-Measured Load-Sediment in the lowest portion of the water column that cannot be measured with most samplers

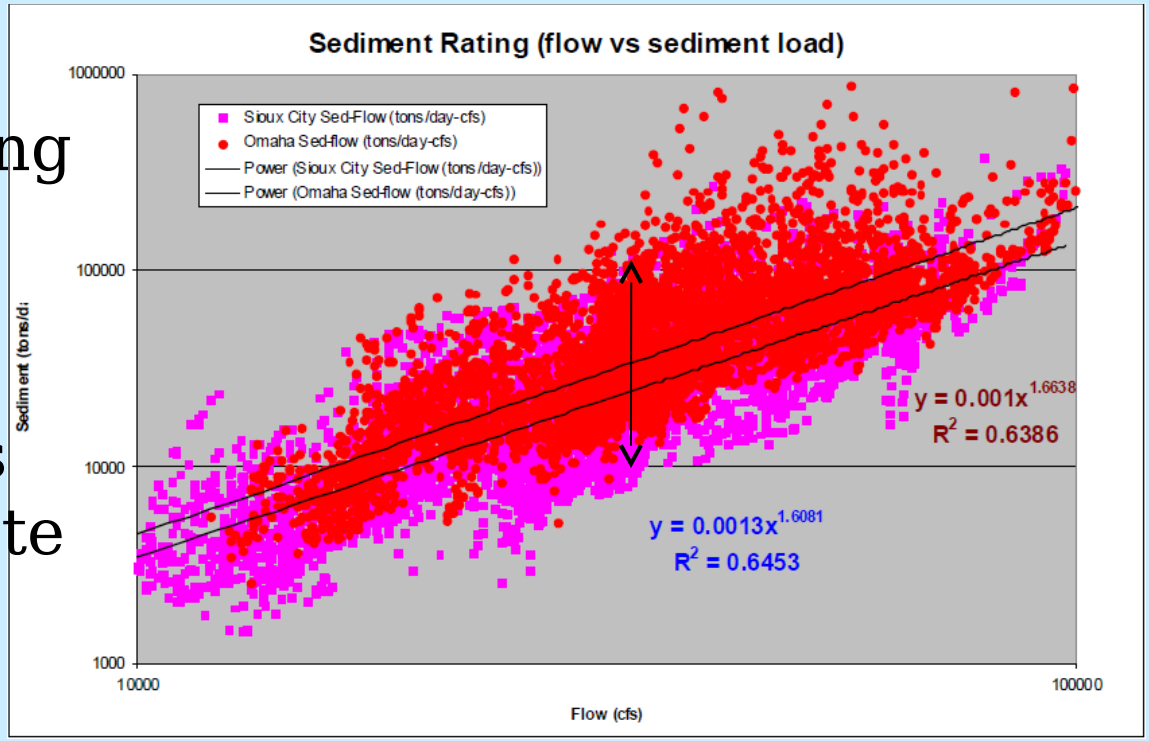
Bed Load-Sediment that creeps or hops along bed (coarse material)

Bed Material Load – sediment that exchanges with and is found in measureable quantities in bed

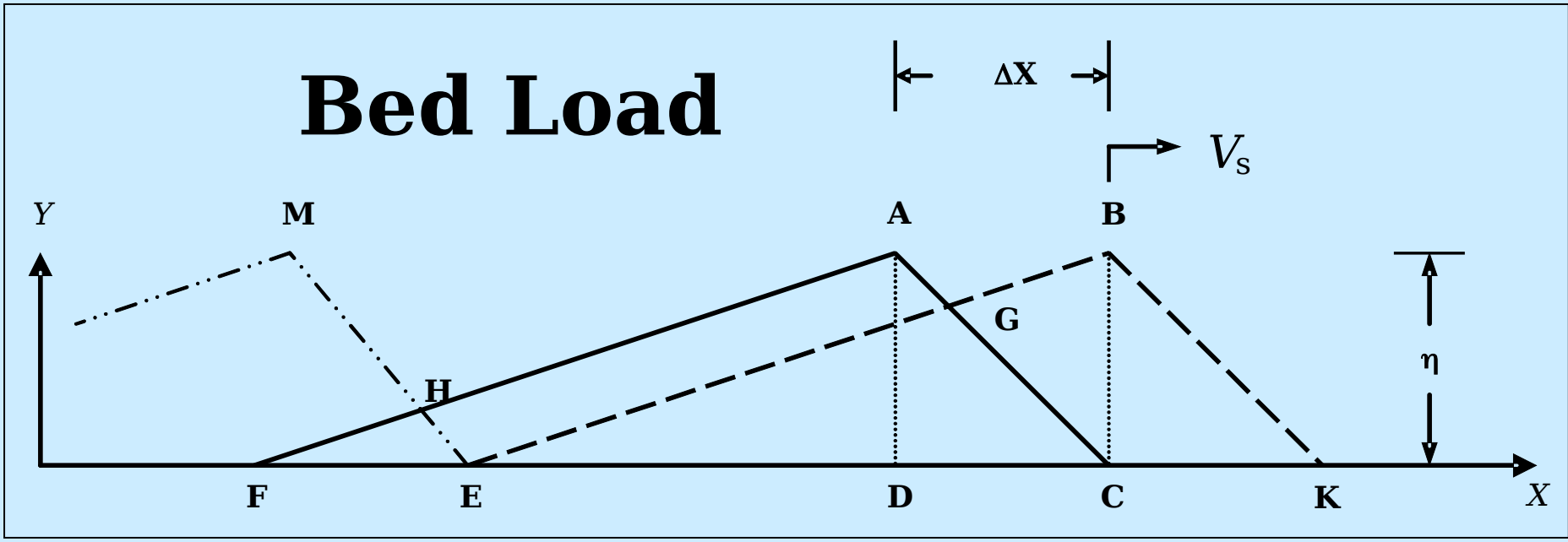
Suspended Load Curves
(based on measured SS)

Suspended sediment can be measured using samplers

A plot of suspended sediment load versus water discharge. Note order of magnitude variation.



ed Sediment Load (tons/day) = Sediment Concentration (mg/L) * Water Discharge (cfs) *

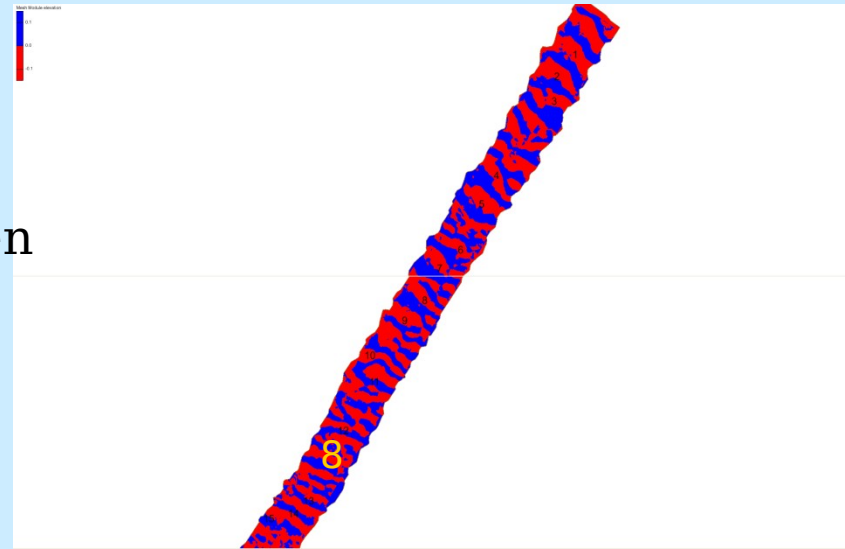


Bed load moves in waves at a certain speed (or celerity). The celerity (c) is given by dividing the distance Δx by time Δt.

Problem is that measuring c is difficult and expensive, and calculating it is uncertain even with good models and data.

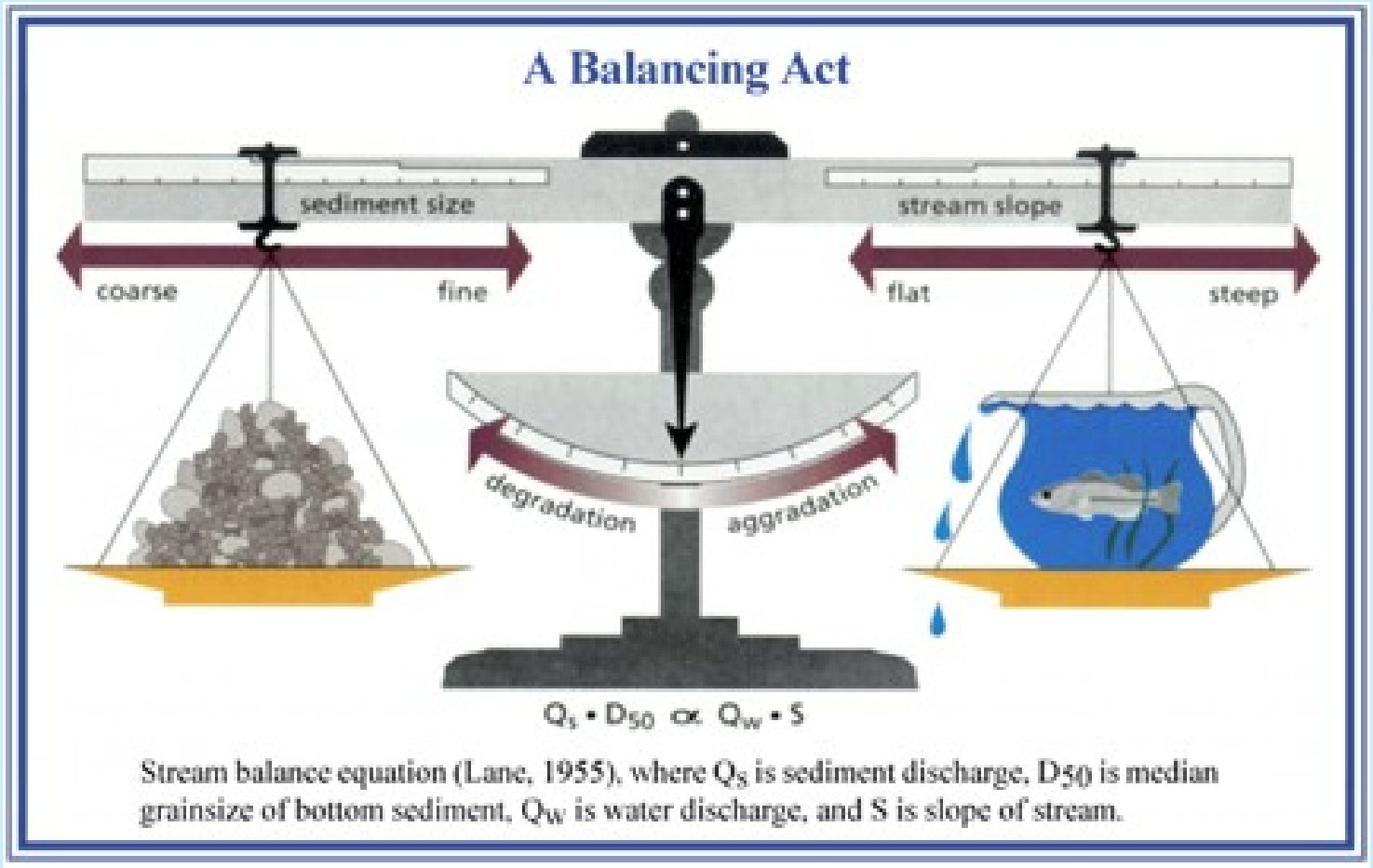
Often we just assume that bed load is 5% to 15% of the total sediment load.

Sketch & Bathymetry from Dvd Abraham and Thad Pratt, ERDC



Calculating Sediment Transport

- There are dozens of sediment transport functions that predict sediment transport based on:
  - sediment size, weight, and fall velocity
  - water velocity and depth
  - channel width
  - channel slope and roughness
  - water temperature
- Many assumptions are made
- Choose functions appropriate for your conditions


A Balancing Act
sediment size
stream slope
coarse
fine
flat
steep
degradation
aggradation
$Q_s \cdot D_{50} \propto Q_w \cdot S$
Stream balance equation (Lane, 1955), where Q_S is sediment discharge, D_{50} is median grainsize of bottom sediment, Q_W is water discharge, and S is slope of stream.

e's Balance says that sediment discharge and sediment
n size tend to balance against water discharge and slope

Sources, Sinks, Pathways

- Sources
  - Bed
  - Banks (Bluffs)
  - Ravines & Gullys
  - Watershed

- Watershed Sources depend on:
  - geology and topography of the watershed
  - magnitude, intensity, duration, and distribution of rainfall
  - vegetative cover; and the extent of cultivation and grazing.

- Regression methods are used to develop soil loss relationships

Sources, Sinks, Pathways

- Sinks
  - Floodplains
  - Valley side slopes
  - Deltas
  - Off - channel areas
  - USACE Dredges

- Most rivers cannot transport all of the sediment that is eroded within its channels and watersheds, so every river system has sinks for sediment.

Sources, Sinks, Pathways

- The capacity of a stream to transport sediment depends on hydraulic properties of the stream channel and sediment properties

Sediment Transport = F (hydraulic properties & sediment properties)

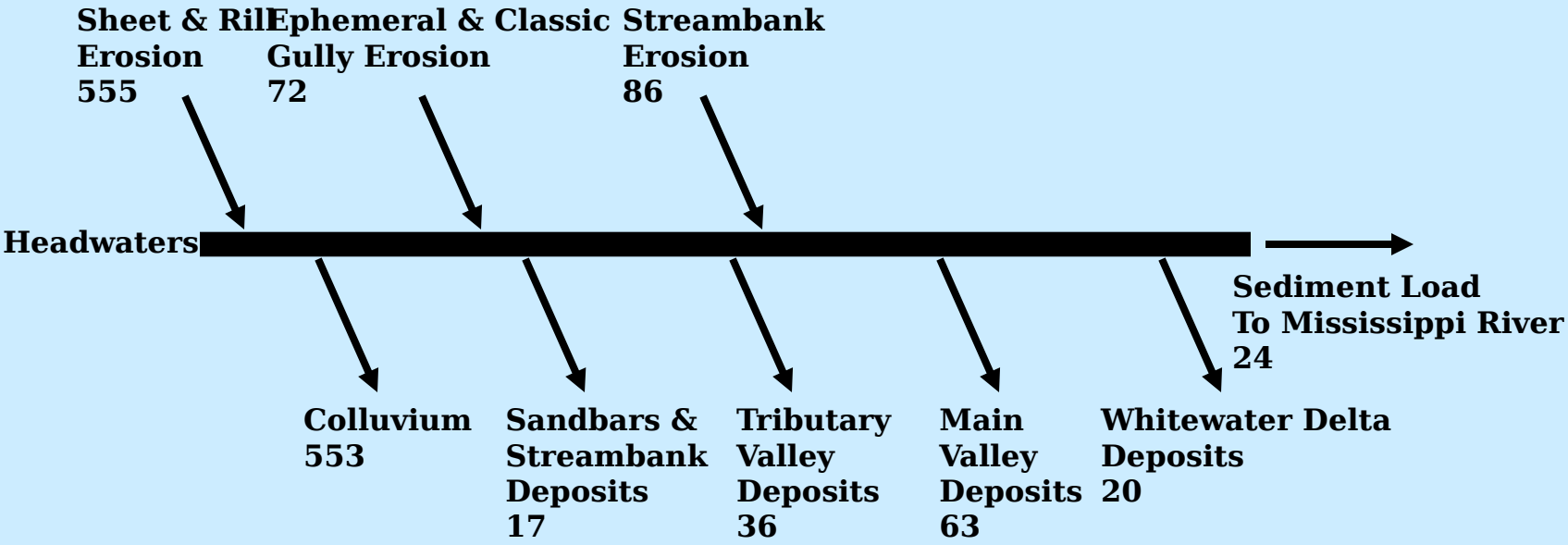
slope
velocity
channel geometry
roughness

grain size distribution
cohesiveness

Sediment Budgets, Watershed Scale

Whitewater River Sediment Budget,
NRCS, 1965 to 1994
Sources of sediment estimated by AGNPs model
Sinks determined by historic survey comparison

Sources (1000's tons/year)


Sheet & Rill Erosion 555
Ephemeral & Classic Gully Erosion 72
Streambank Erosion 86
Headwaters
Sediment Load To Mississippi River 24
Colluvium 553
Sandbars & Streambank Deposits 17
Tributary Valley Deposits 36
Main Valley Deposits 63
Whitewater Delta Deposits 20

Sinks (1000's tons/year)

Only 24,000 tons/year of the total 713,000 tons/year from sheet and rill erosion, ephemeral & classic gully erosion, and streambank erosion is transported to the mouth of the river.

Sediment Effects on Water Quality

- The majority of sediment transport in a given year occurs during seasonal high water events
- Sediment transport during other times can have a significant effect on underwater light, nutrient loads, substrate.

Suspended Sediment Concentration (SSC) is Different than Total Suspended Solids (TSS)

pling: Iso-kinetic sampling where the velocity and concentration in the intake is equal to the velocity and concentration in the surrounding water is requ ediment samples that represent the true sediment load
S protocols by Edwards and Glyssen (1999)
s (2005)

pling (e.g. automatic water samplers (or pump sample e not iso-kinetic, however this is not a problem for fin ts.

analytical method uses the entire water-sediment n the analysis. (ASTM D-3977)

alysis entails withdrawal of an aliquot (or part) of the original sample for subseq (SM 2540-D). It is OK to use if the sediments are fine sediments, but don't use i ts are in the sample.

information see http://water.usgs.gov/osw/techniques/sediment.html

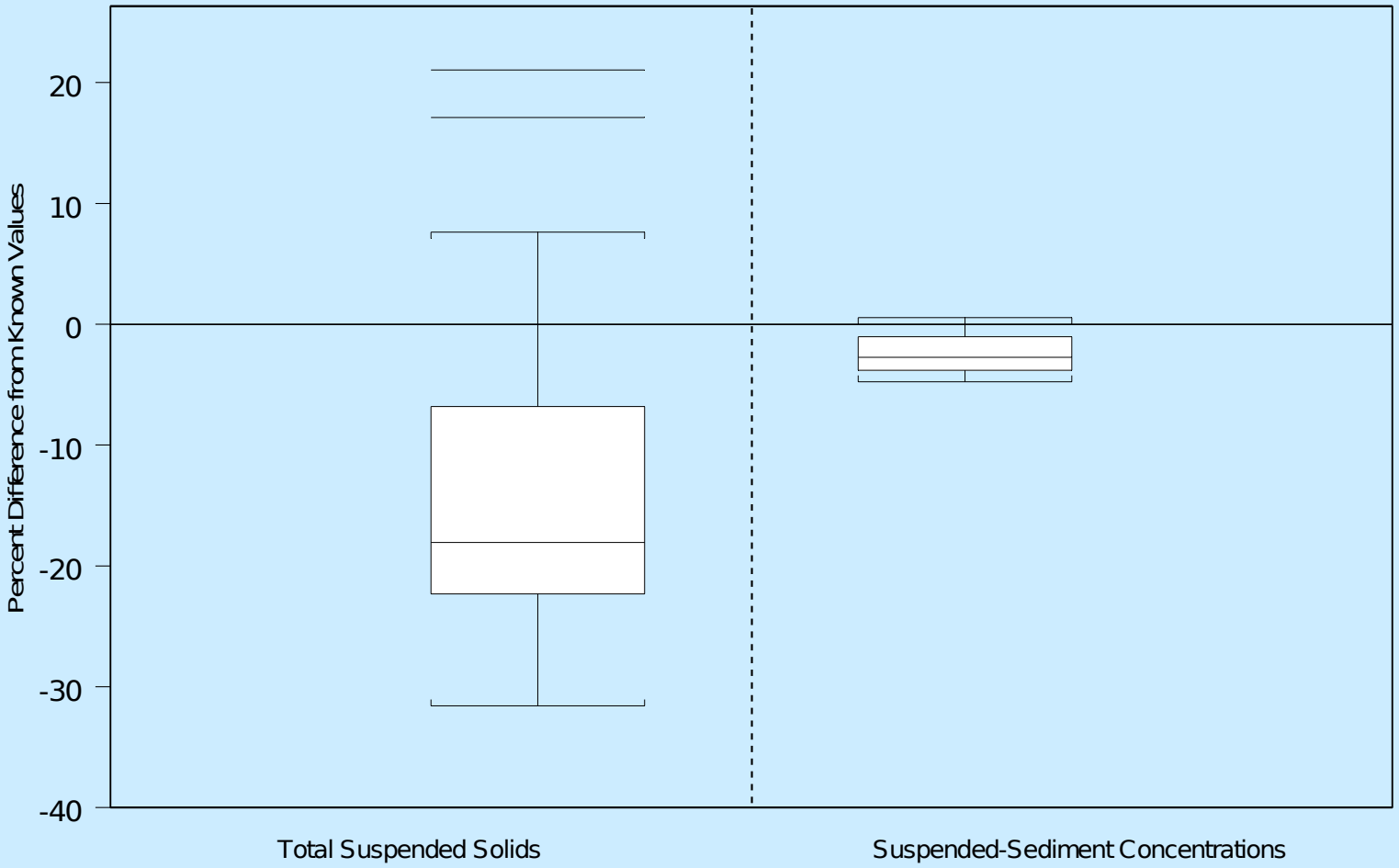
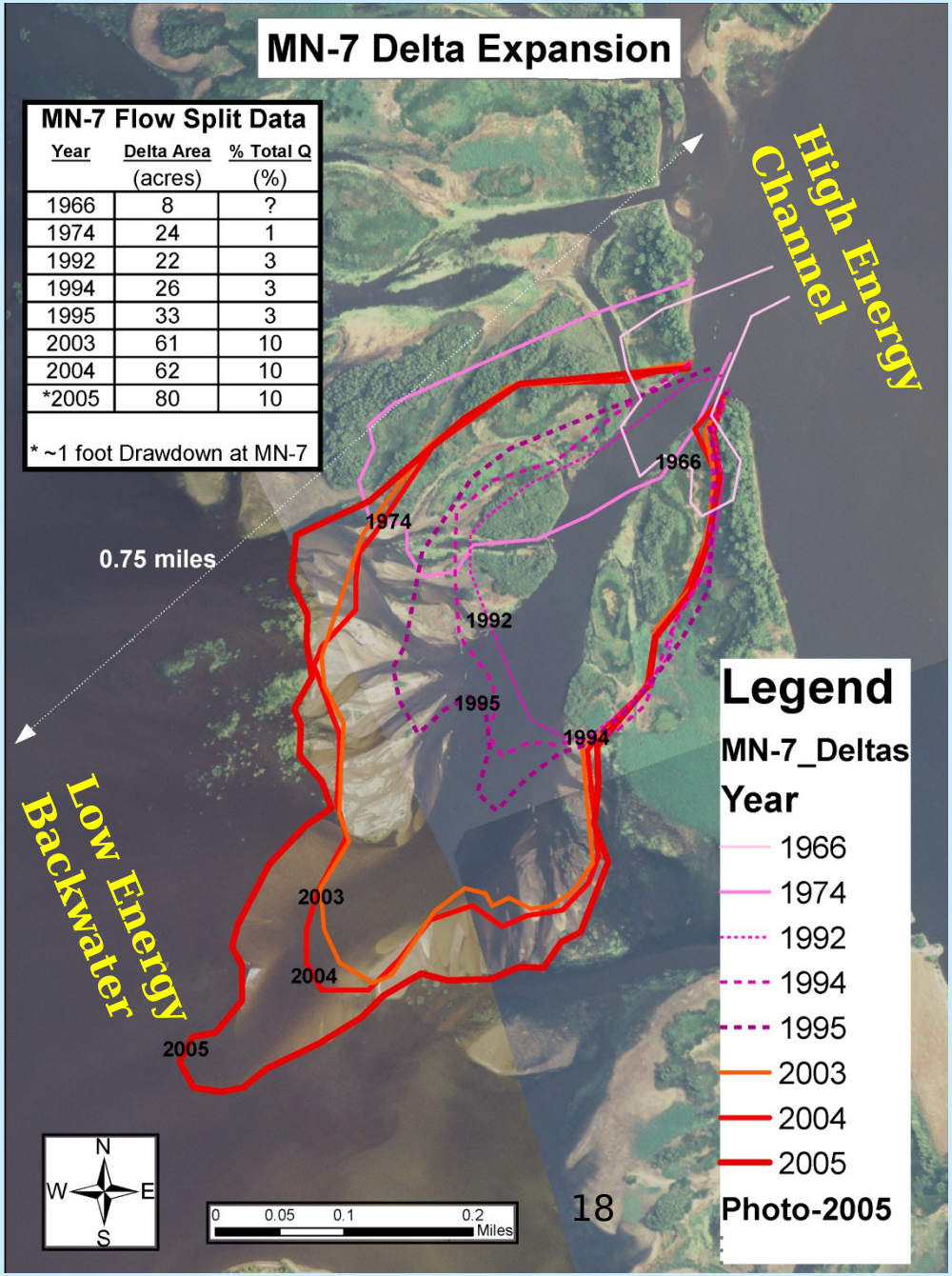


Figure 6. Boxplots of analytical results of total suspended solids and suspended-sediment concentrations determined from quality control samples.

Data from USGS

Geomorphology

- Geologic science of landscape formation
- Fluvial Geomorphology
  - landscape formation by streams



Watershed and Channel Alteration will change H&H Causing Geomorphic Responses Including:

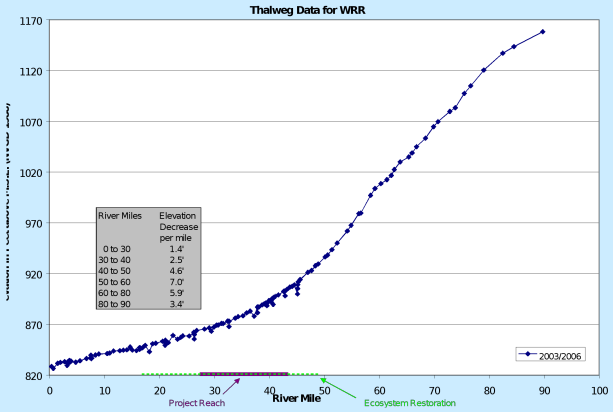
- Channel incision
- Channel plugging
- Land loss along channels
- Gullying
- Floodplain deposition

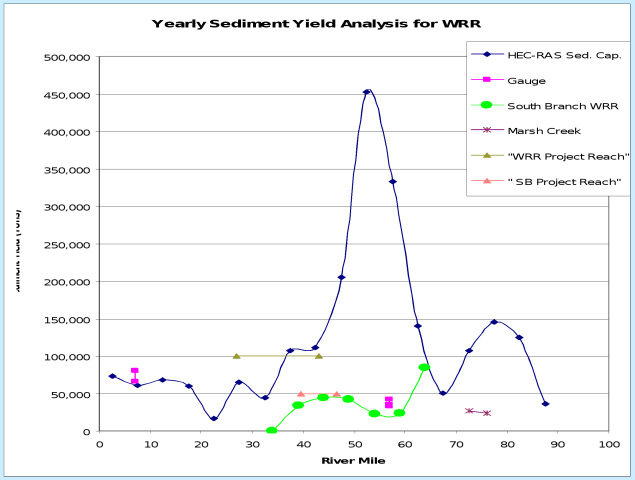
Geomorphic Responses may Affect:

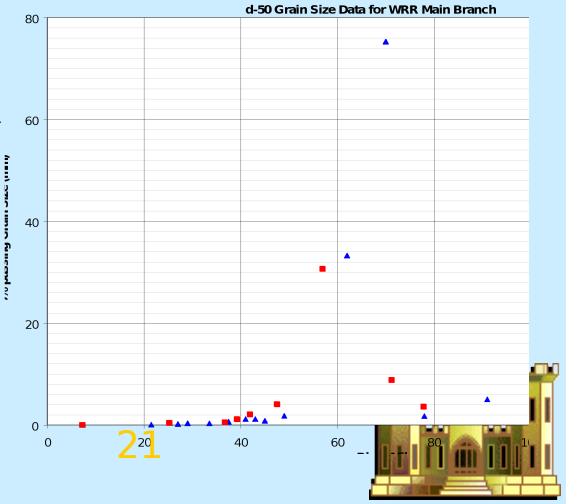
- Infrastructure: Bridges, FRM
- Human uses: Drinking water, recreation, agriculture
- Aquatic Habitat
- Commercial Navigation
- Water Quality: Underwater light, nutrients, contaminants

Spatial Scales

- Changes in:
  - Channel geometry
  - Slope
  - Roughness
- Cause changes in
  - Sediment transport
  - Geomorphic processes
  - Channel Capacity







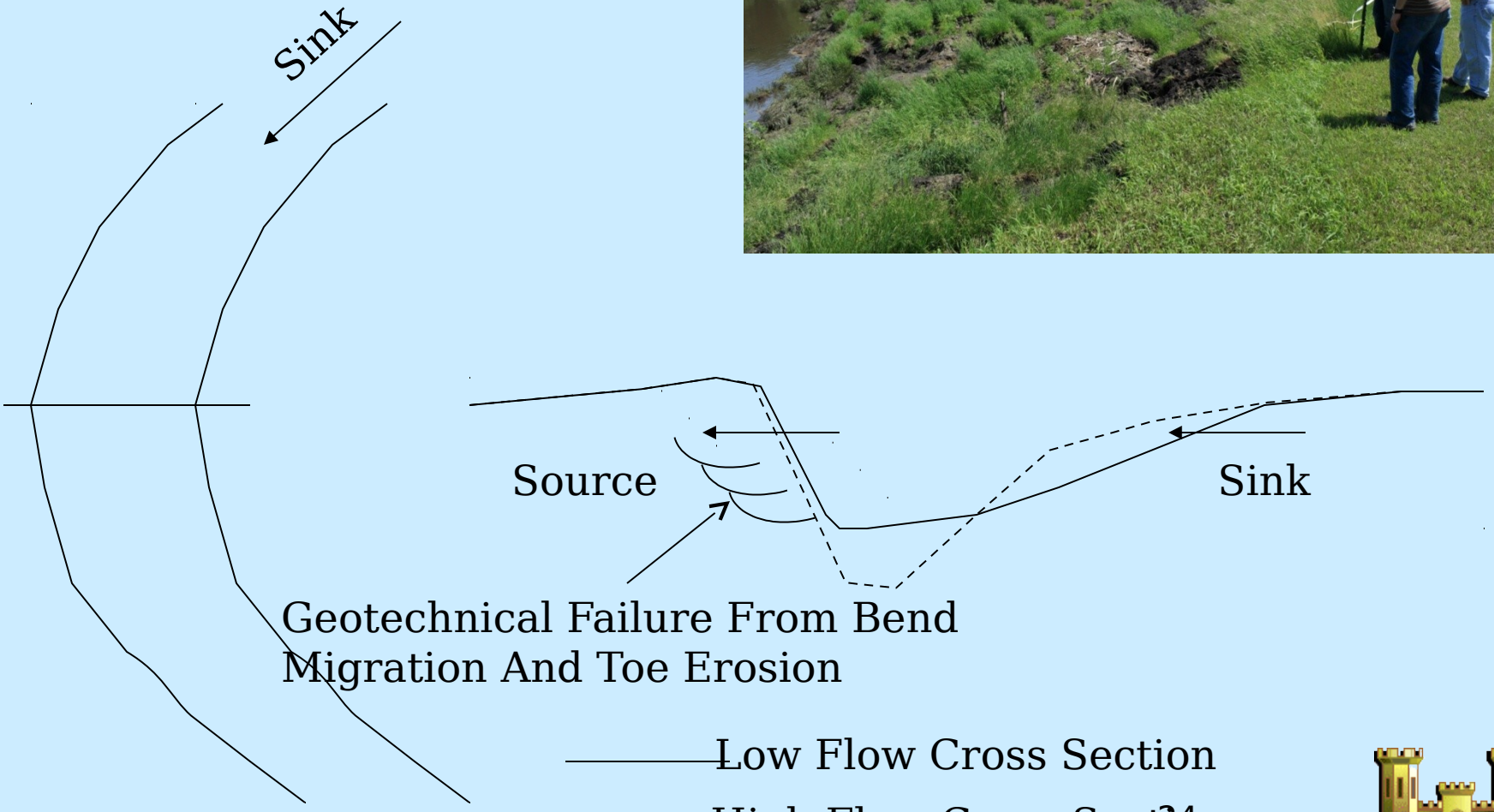
Time-Scales

- Annual geomorphic changes like sand bar migration, bank erosion, point bar building occur due to seasonal high flows
- Long-Term geomorphic change like incision or delta building or loss might be natural or anthropogenic.
- Climate variation, watershed development, channelization, dams, urbanization affect geomorphic change at both scales.

Use Multiple Tools for Sediment Transport and Geomorphological Analysis

- Field Investigations
  - Existing conditions substrate, bankfull conditions, vegetation, discussion with local experts
- Surveys:
  - Cross sections, profiles, sediment cores
- Analytical Techniques
- Numerical Models:
  - Watershed models
  - River models
- Aerial photo comparisons
  - Change from Historic conditions
- Sediment Budgets
- Specific Stage Discharge Analysis

Erosion of a River Bend



Flood of Record Washed Out Railroad, Undermined Houses

River Meandering and Effects of 0.2 % Chance Flood

Legend
Wild Rice River Center Line (2003)
Cross Sections

Wild Rice River Meander a

500 250 0

Legend
Wild Rice River Center Line (2003)
Cross Sections

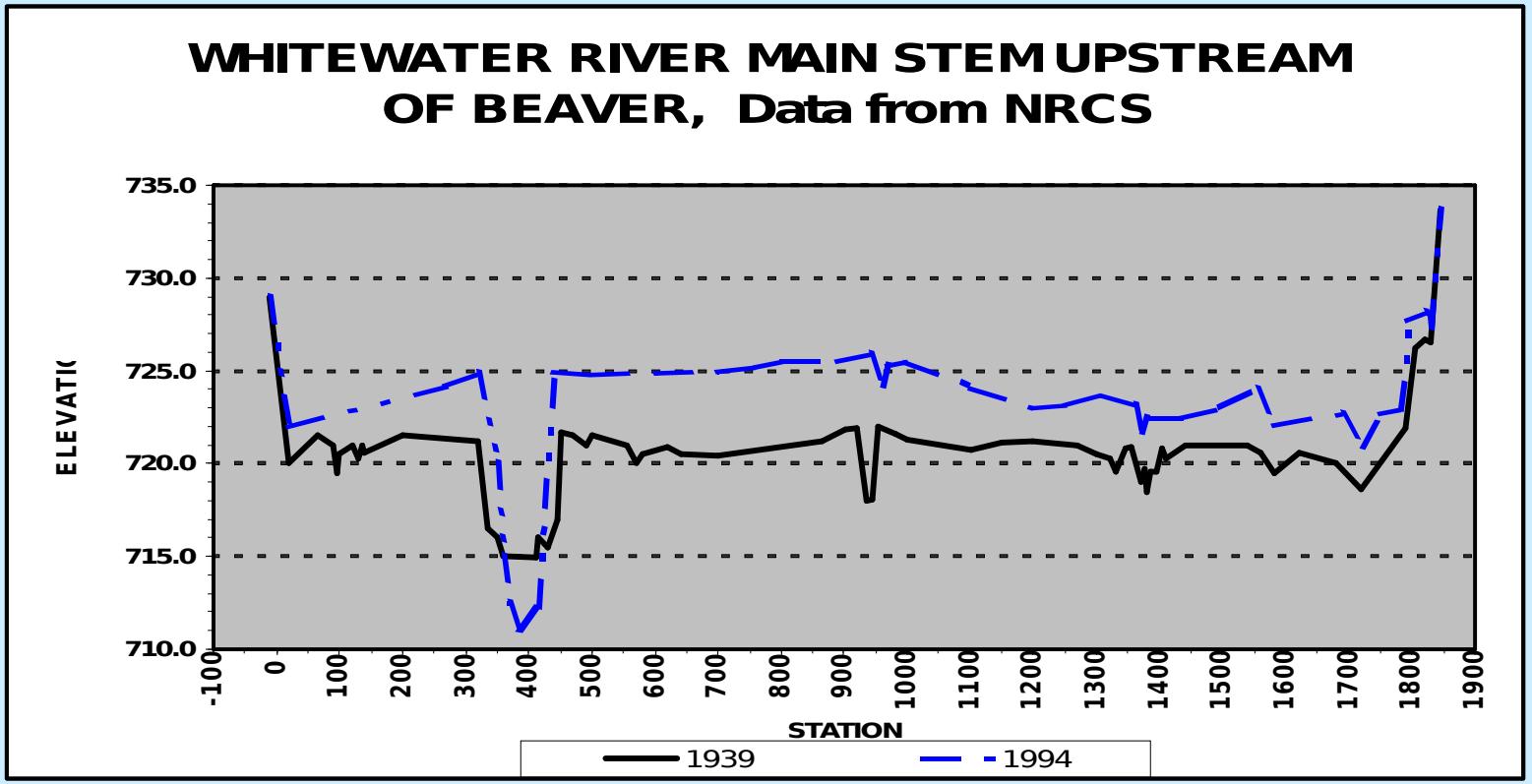
Wild Rice River Meander at Mile 48

500 250 0 500 Feet

St. Paul District
HYDRAULICS
HYDROLOGY
US Army Corps of Engineers®

Geomorphic Response to Watershed Development

- Floodplain Deposition, Channel Incision



Whitewater River Avulsion
August 2007
Highway 61 Bridge
Canadian Pacific RR Bridge
New Mouth of
Whitewater River
Whitewater River shortened
By about 6,000’
Old Mouth of
Whitewater River

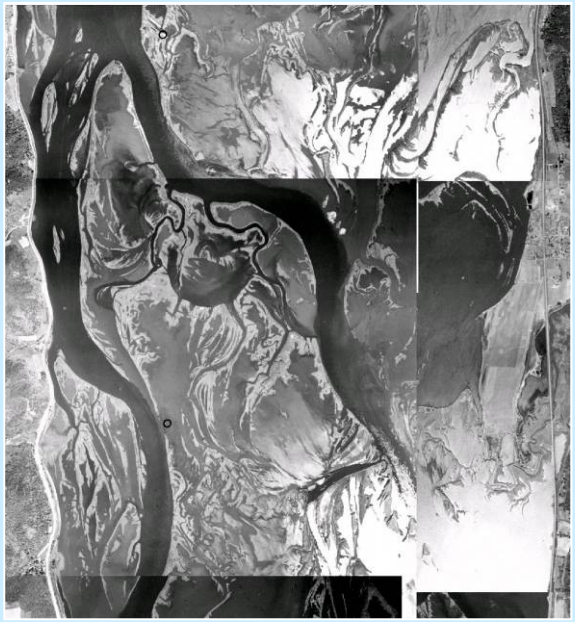
Culvert Outlet Failure

Channelization

Geomorphic Response to Raised Water Levels In Lower Pool 8

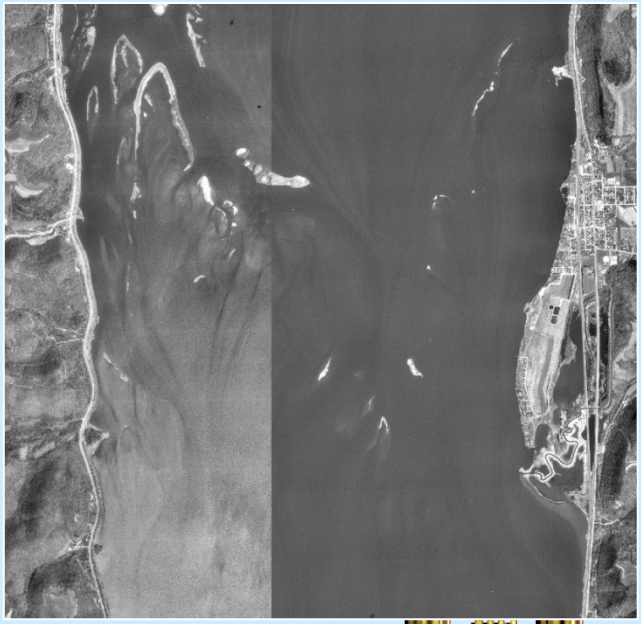
- Island Loss And Erosion
- Increased Connectivity
- Sediment Deposition

1938



1954

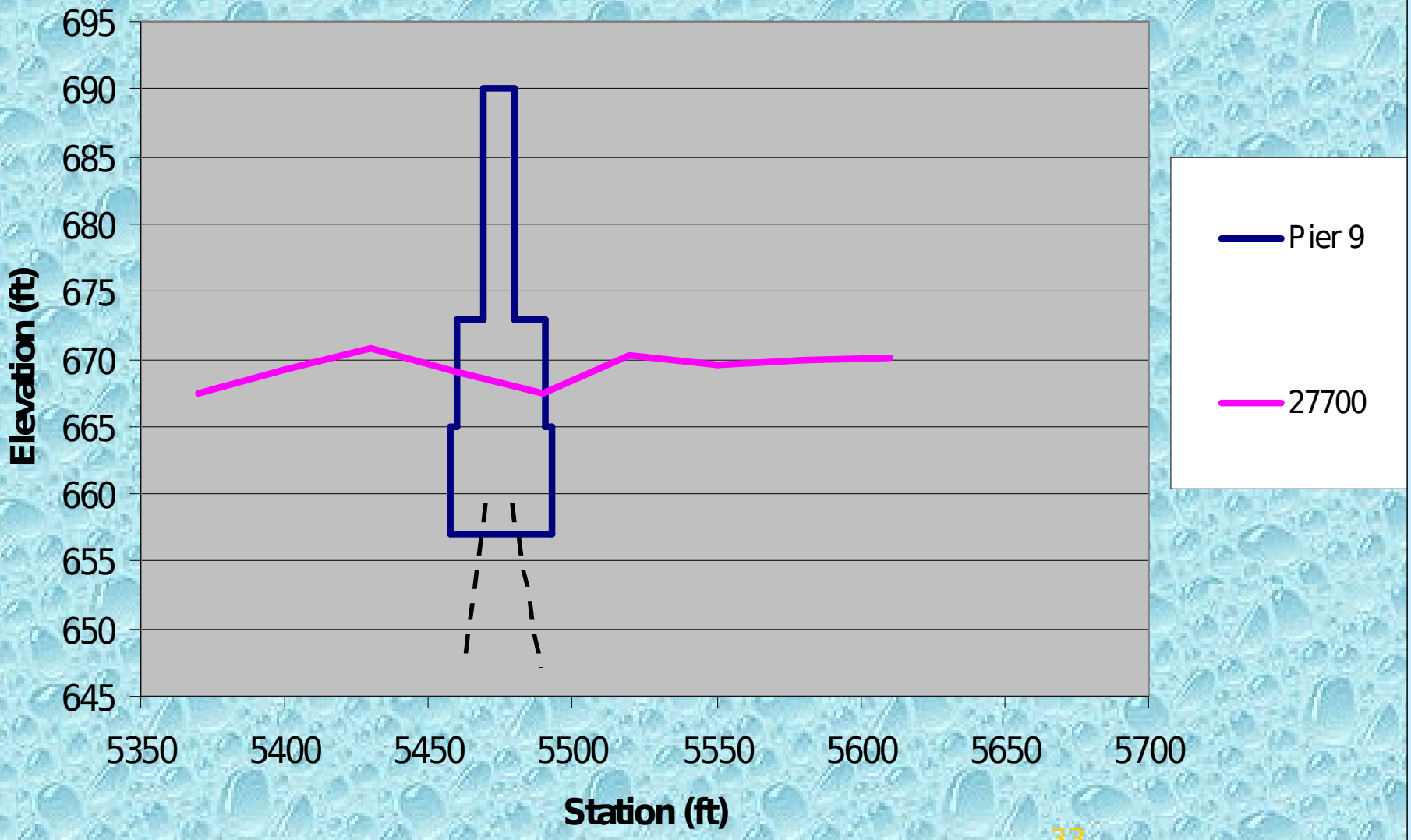
1991



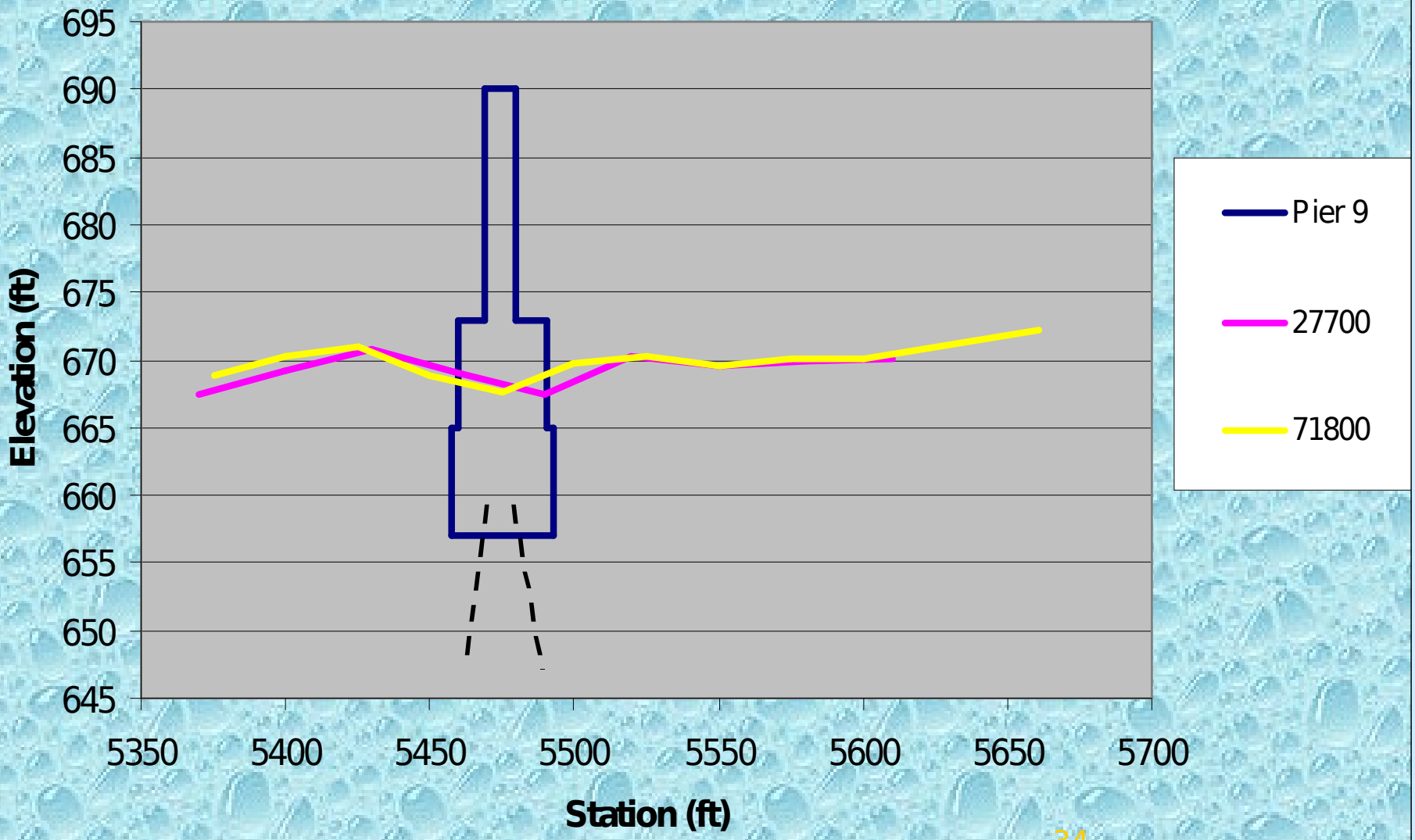
Bridges

- Usually footings are deep enough to handle a certain amount of scour.
- Changed hydrological conditions (climate variation, land use change) or changed hydraulic conditions (dam removal, debris) can create greater scour levels

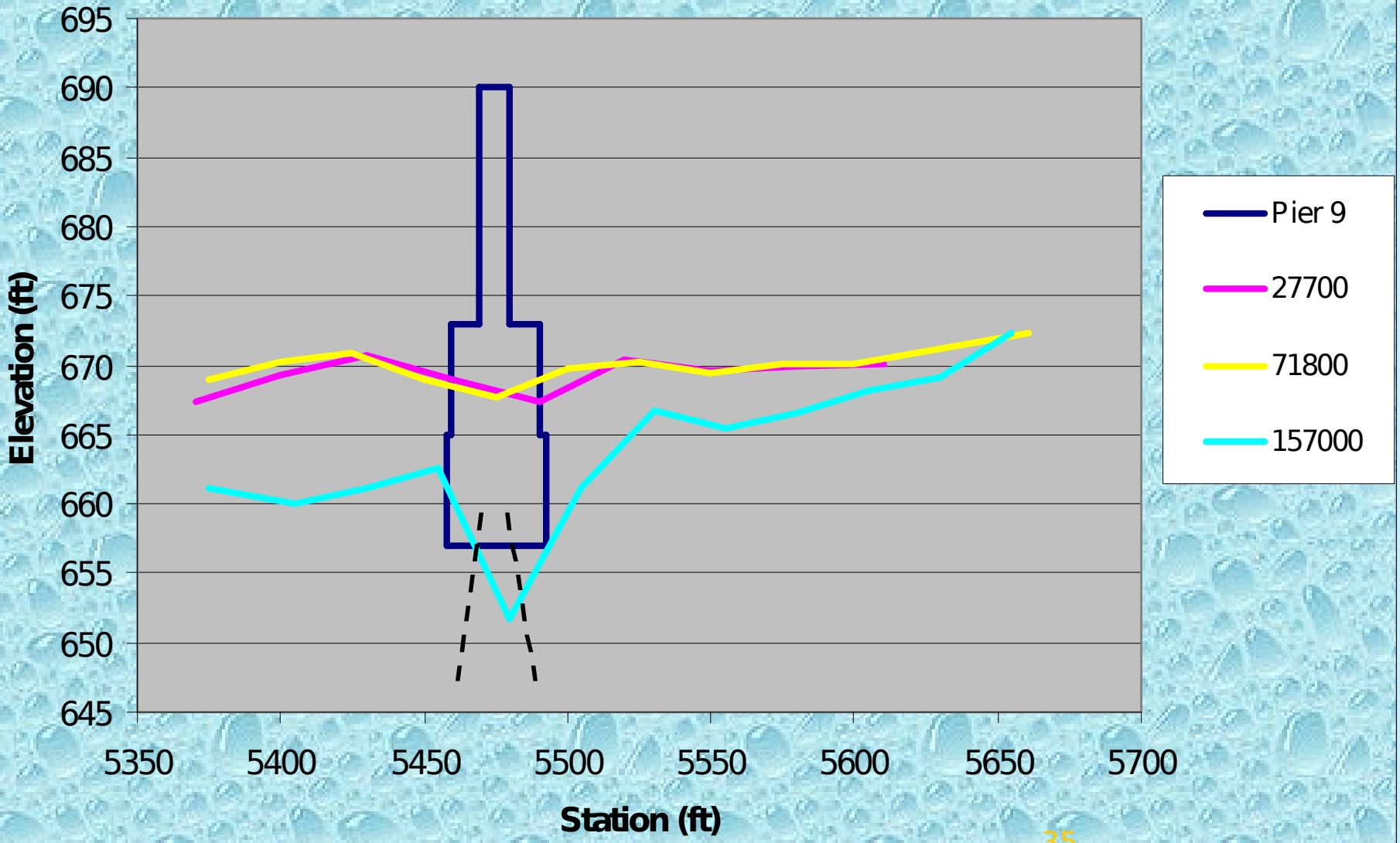
Lafayette Bridge: 1969 Rising Flood



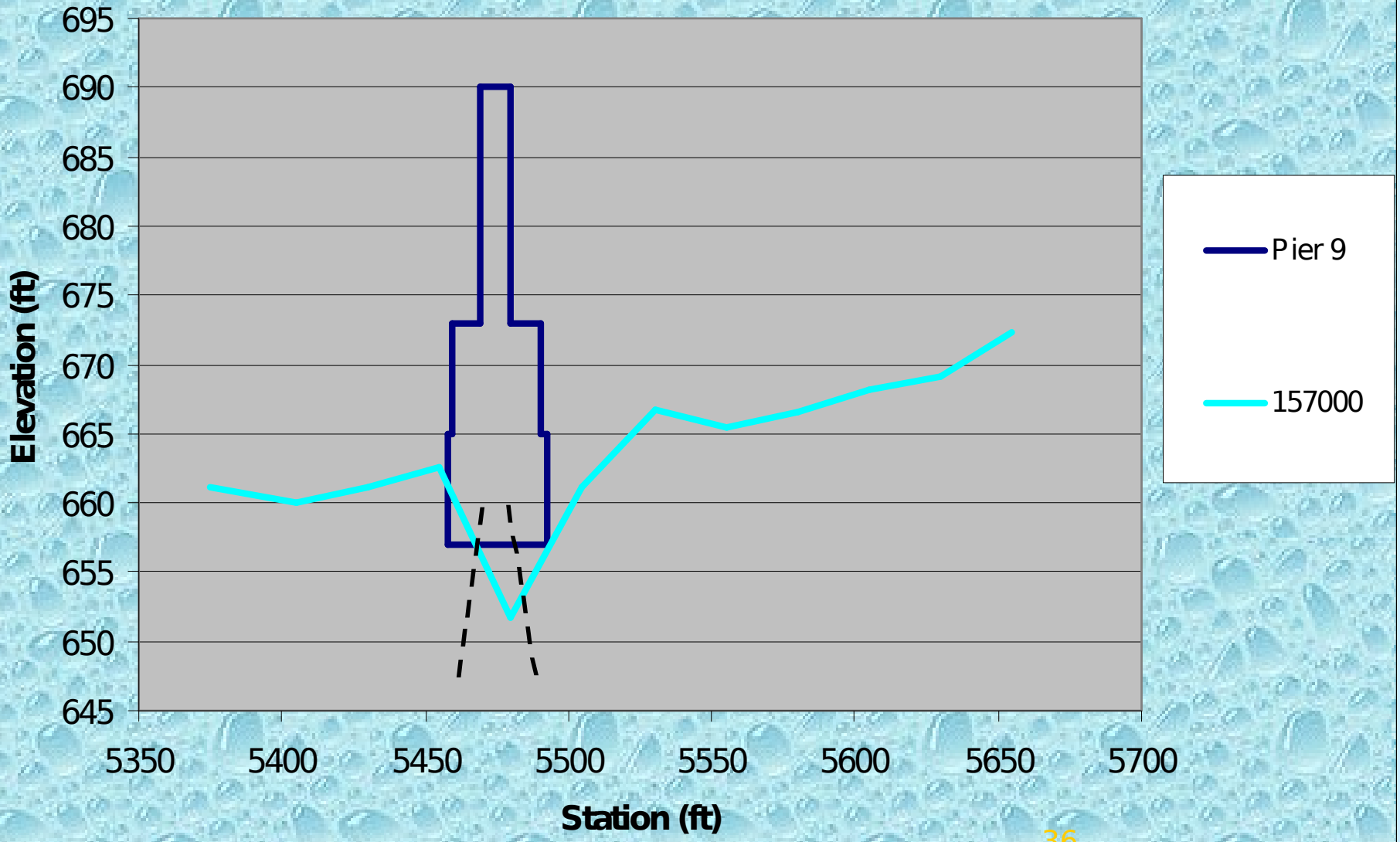
Lafayette Bridge: 1969 Rising Flood



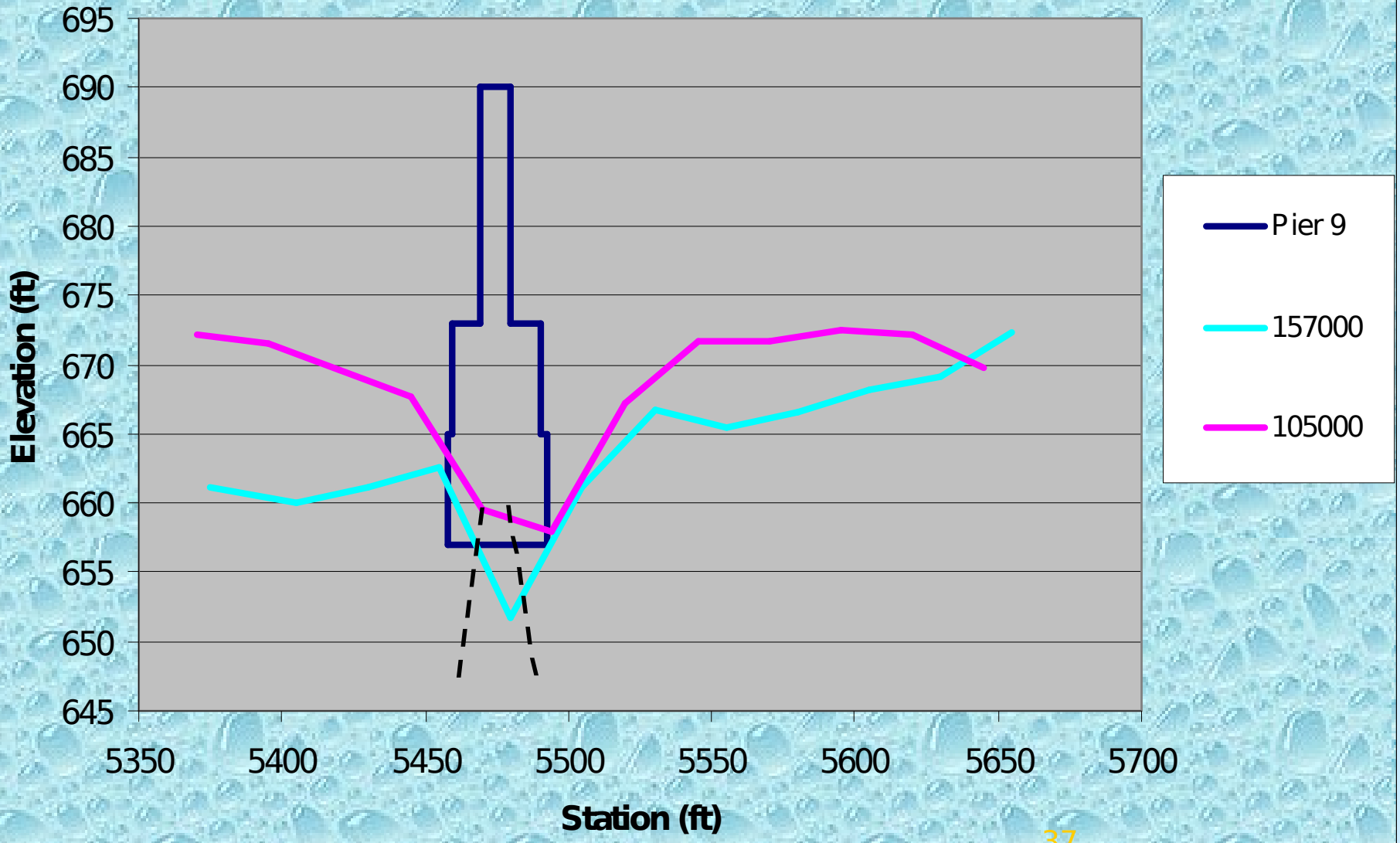
Lafayette Bridge: 1969 Rising Flood



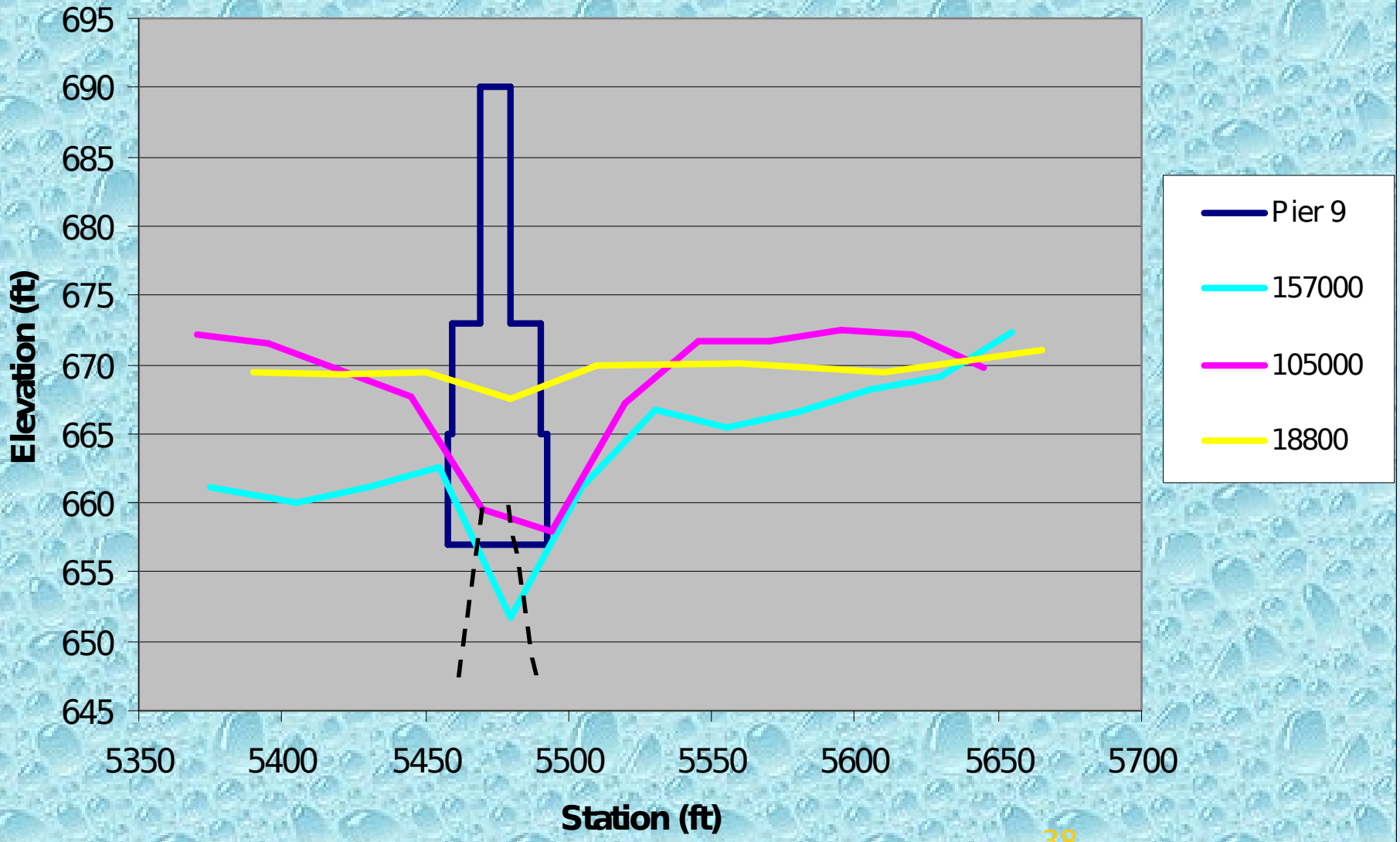
Lafayette Bridge: 1969 Falling Flood



Lafayette Bridge: 1969 Falling Flood



Lafayette Bridge: 1969 Falling Flood



Bridge 87015
TH 212 over Minnesota River
Overflow Abutment Fill and Approach Panel Lost

Q500 = 7,300 cfs
Q1997 = 10,000 cfs

Excerpts from Inspectors Notes:

4/4 108” below NW, channel has shifted to east

4/5 69” from SE wingwall, deck vibrating, riprap eroded, looking down through water.

4/6 2:00 PM Panel undermined, water flowing

Bridge 54002

Bridge is still structurally stable, but from the travelers perspective it failed.

Long Lake Water Control Structure after 2001 Flood

~ The End ~